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The Use of Centrifugal Flow Pumps in a Model of Experimental Right Heart Failure

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RIGHT VENTRICULAR failure is not an uncommon complication of cardiac procedures and is seen in other clinical situations such as right ventricular infarction, pulmonary hypertension, and pulmonary embolism.

Right ventricular failure has been characterized by acute dilatation and paradoxic motion in systole, a rise in right atrial pressure, a fall in mean systemic and pulmonary arterial pressures, and a drop in left atrial pressure and cardiac output. Right ventricular failure has been managed clinically by optimizing preload and administration of inotropic agents. More profound failure may necessitate the use of mechanical support in the form of pulmonary arterial balloon counterpulsation and right-sided cardiac bypass.

Right ventricular failure has been induced experimentally by a variety of methods and has been overcome in the laboratory by using intraventricular balloon pumps, pulmonary arterial balloon pumps, pneumatic assist devices, and centrifugal flow pumps.[1] In the literature, however, there are no models of acute, isolated, right heart failure due to infarction treated by mechanical assistance using centrifugal flow pumps that do not further compromise ventricular function.

The purpose of this study was to answer three questions: Can ischemic right ventricular failure be induced experimentally without ventricular arrhythmias or opening the ventricle? Can a centrifugal flow pump overcome this failure? Is there a difference between the vortex (Biomedicus, Minneapolis, MN) and rotor impeller (Centrimed, Hopkins, MN) type of pump used?

Materials and Methods

Right ventricular ischemic dysfunction was induced in eight adult swine by surgical ligation of branches of the right coronary artery. Dysfunction and failure were demonstrated by a clear demarcation in the right ventricular myocardium with paradoxic motion in systole, a rise in the mean right atrial pressure (from 7.8 to 10.6 mmHg, $p < .05$), a fall in left atrial pressure (from 7.2 to 6.4 mmHg, $p < .10$), a drop in mean pulmonary arterial pressure (from 17 to 14 mmHg, $p < .10$), a fall in mean systemic arterial pressure (from 89.5 to 58.6 mmHg, $p < .01$), and a drop in cardiac output (from 4 to 2.5 liters/min, $p < .01$).

Right-sided circulatory support was accomplished by two separate centrifugal flow pumps (Centrimed and Biomedicus) with inflow from a right atrial cannula and outflow to a polytetrafluoroethylene (PTFE) graft anastomosed to the proximal pulmonary artery (Fig. 1). The pig was placed on one pump (as determined by coin toss) for 15 minutes with flows adjusted until the preli-

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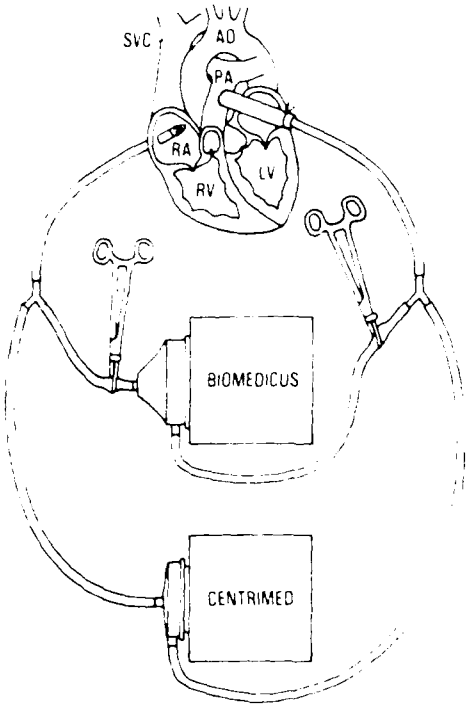

FIG. 1. Centrifugal flow pump dual set-up. The pumps are placed parallel to each other to facilitate switching back and forth during the experiment. The outflow is from a straight cannula from the right atrium through the right atrial appendage. The inflow is through a cannula tied to a PTFE graft anastomosed to the proximal pulmonary artery.

gation baseline values were reached for the values outlined earlier. The pump was then turned off and the values allowed to return to postligation baseline. The next run involved the other type of centrifugal flow pump. After 15 minutes the values were again allowed to return to postligation baseline. The process was repeated using the original pump. The pigs were then killed.

Results

The pumps significantly increased the mean systemic arterial pressure and restored cardiac output to preligation levels ($p < .01$ for each, Fig. 2 and 3). In addition, right atrial

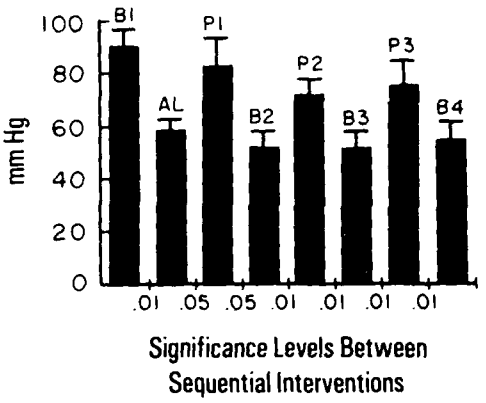

FIG. 2. Mean systemic arterial pressure (mmHg). B1 is the initial baseline determination and AL is the pressure after ligation of the right coronory arterial branches. P1, P2, and P3 are the pressures during serial pump runs, and B2, B3, and B4 are the pressures after the pump interventions when the values were allowed to return to baseline. The bars represent standard errors of the mean.

pressure returned to baseline levels, as did the left atrial and mean pulmonary arterial pressures. There was no observed difference

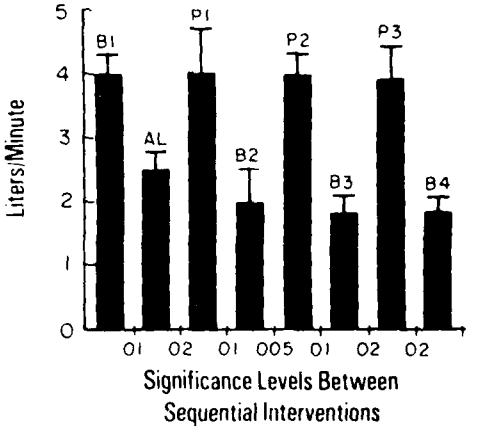

FIG. 3. Cardiac output in (liters/minute). B1 is the initial cardiac output and AL is the output after ligation of the right coronary arterial branches. P1, P2, and P3 are the cardiac outputs during serial pump interventions and B2, B3, and B4 are the outputs after the pump runs when the values were allowed to return to baseline. The bars represent standard errors of the mean.

between the performance of the two types of centrifugal flow pumps in any of the values measured.

Discussion

Understanding of the function of the right ventricle is still unclear and controversial. In the past, authors described experiments in which destruction or exclusion of the right ventricle did not result in serious hemodynamic derangement. On the other hand, others described similar experiments that resulted in clear failure.

What seems to be true is that in certain situations one can live without a right ventricle. This is particularly true of patients with tricuspid atresia who undergo a Fontan procedure, which effectively bypasses the ventricle. These surviving patients are, however, free of any pulmonary hypertension.

Other studies have shown that the right atrium by itself is unable to provide enough flow to maintain cardiac output. Any acute dilatation of the atrium or pulmonary hypertension makes the chamber even more prone to failure.[2]

It has been postulated that the seemingly unimpaired ventricular function after destruction of the right ventricular free wall is caused by a strong septal contribution and transmission of left ventricular energy through encircling bands of muscle. Surely the typical cardiac patient with left-sided dysfunction would be at risk for right ventricular failure because this assistance by the left ventricle would be in jeopardy. We see then that only in special situations is the right ventricle indispensible.

To date, right ventricular assistance has been provided by intraventricular and pulmonary arterial balloon counterpulsation, pneumatic pumps and centrifugal flow pumps.[3-5] Most of these modalities have met with some success but drawbacks have been reported, including retrograde flow, pulmonary parenchymal damage, and prohibitive cost.[6]

The centrifugal flow pumps are easy to use and set up, are relatively inexpensive, and are readily removed when no longer needed. In addition, when they are connected to the right atrial appendage for outflow and a graft is anastomosed to the pulmonary artery for inflow, the pumps add no additional myocardial damage or arrhythmia, as reported by other authors.

Conclusion

Pigs can be used as a reliable model for acute right heart failure. In addition, the results indicate that right ventricular dysfunction can be effectively overcome by either type of centrifugal flow pump, which may be of clinical benefit to patients with acute right heart failure.

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